Correlation of Full-Scale Isolated Proprotor Performance and Loads

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Introduction

A full-scale isolated proprotor test is currently being conducted in the USAF National Full-Scale Aerodynamics Complex (NFAC) 40- by 80-Foot Wind Tunnel at NASA Ames. The test article is a 3-bladed research rotor derived from the right-hand rotor of the AW609; this rotor was manufactured by Bell Helicopter under contract to NASA. In this paper, this research rotor is referred to as "699". The test, nearly completed, is an integral part of the initial checkout test of the newly developed Tiltrotor Test Rig (TTR), whose purpose is to test advanced, full-scale proprotors in the NFAC. Figure 1 shows the TTR/699 installed in the 40- by 80-Foot test section. The TTR rotor axis is horizontal and the rig rotates in yaw on the wind tunnel turntable for conversion (transition) and helicopter mode testing.

Figure 1. TTR/699 installed in the USAF NFAC 40- by 80-Foot Wind Tunnel.

To date, a substantial amount of wind tunnel test data has already been acquired. The completed operational conditions include hover, airplane mode (cruise, wind tunnel airspeed V=61 to 267 knots), and the helicopter and conversion conditions (with a comprehensive sweep of the TTR yaw angle ranging, to date, from 90-deg yaw helicopter mode to 30-deg yaw conversion mode, at varying airspeeds). This 699 proprotor performance and loads correlation study uses these newly acquired wind tunnel test data.

This paper represents the third analytical study, coming after two earlier analytical studies on the TTR/699; that is, a 2018 paper on pre-test predictions of 699 performance and loads, Ref. 1, and an upcoming January 2019 paper on aeroelastic stability analysis of the TTR/699 installed in the 40- by 80-Foot Wind Tunnel, Ref. 2. Reference 8 will present an overview of the entire TTR/699 test program. For completeness, Ref. 3 addresses the development and initial testing of the TTR. Background information on the TTR effort at NASA Ames can be found at the Aeromechanics website: https://rotorcraft.arc.nasa.gov/Research/Facilities/ttr.html .

To the authors' knowledge, the full-scale results presented in this paper are the first of their kind. A literature survey brought up several existing correlation studies, but these were either based on small-scale test data (for example, the studies performed by the University of Maryland) or full-scale aircraft flight test data (for example, flight tests conducted by Bell Helicopter). Separately, the 2009 NASA study involving the JVX rotor is relevant (see Ref. 4). The JVX is closely similar to the 699 in size and aerodynamics, and is accordingly a good reference for performance

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calculations. In Ref. 1 (as mentioned above), pre-test reality checks of the current analytical model were made by comparing JVX and 699 predictions in hover and forward flight (airplane mode).

Analytical Model

The rotorcraft comprehensive analysis CAMRAD II Release 4.9, Refs. 5-7, is used for the analytical predictions. The analytical model has been described in Ref. 1. For the helicopter and conversion conditions, the current trim procedure differs from that of Ref. 1; this correlation study uses the Ref. 2 trim procedure — for a given airspeed, the rotor is trimmed to zero 1P flapping, while increasing the collective (no thrust trim). This is the procedure that is followed during a typical wind tunnel test run.

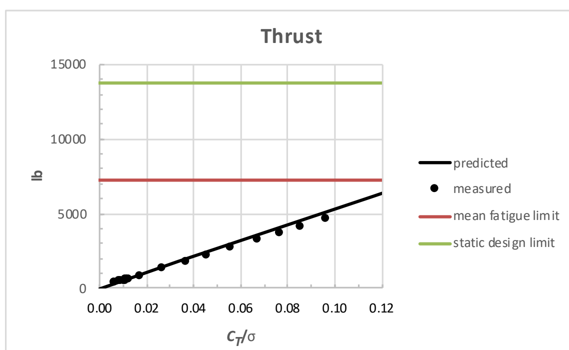
The analytical model used here is identical to that of Refs. 1 and 2. The difference is that the analytical operating conditions presented here are matched to the test conditions actually achieved.

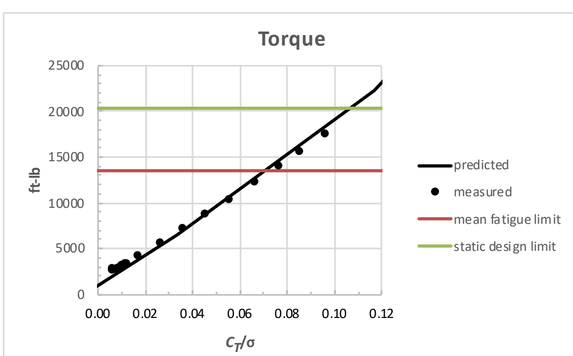
Sample Results

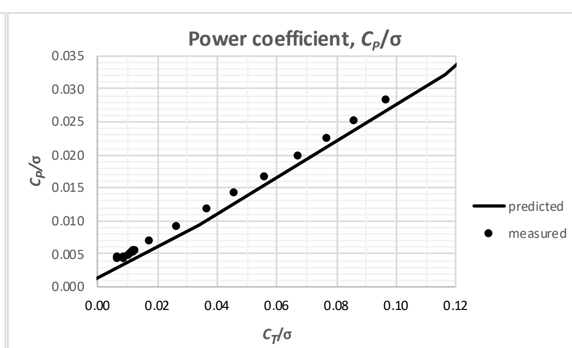
Sample correlation results for the cruise and conversion modes are shown in this abstract. For cruise, results are shown for the thrust, torque, power coefficient C_P/σ, and midspan (0.45R, blade station 70) blade bending moments. Final tare corrections have not yet been applied to the data presented in this abstract. For conversion, results are shown for the trim cyclics, thrust, torque, C_P/σ, pitch link load, midspan blade bending moments, and yoke (flexbeam) bending moments at the inboard location (0.082R, yoke station 12). The conversion mode results include mean and ½ peak-to-peak quantities. The sign convention is as follows: pitch link load: + for tension; flap bending moment: + tip bent up; and lag bending moment: + tip bent toward trailing edge. The cruise and conversion correlation results are given below. The paper will contain a full set of results along with the details.

Cruise (airplane mode)

Figure 2 shows the cruise (axial flow) thrust, torque, C_P/σ, and midspan blade flap and lag bending moments, all vs. the thrust coefficient C_T/σ. The airspeed V=91 knots (rpm=485). The results were initially plotted vs. the collective pitch, but in order to avoid the effect of possible offsets between the analytical and test collectives, the x-axis was changed to C_T/σ. The correlation at this low cruise speed is reasonable.







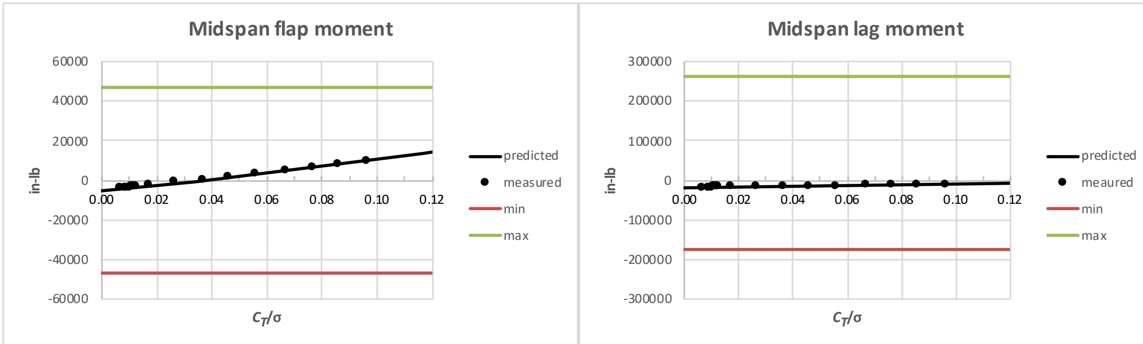


Figure 2. Cruise (axial flow) correlation, V=91 knots (μ=0.233).

Conversion

Figures 3a-3b show the conversion results, all vs. C_T/σ. The TTR was oriented at 45-deg yaw and the airspeed V=92 knots (rpm=569). Figure 3a shows the rotor performance parameters: trim cyclics, thrust, torque, and C_P/σ.

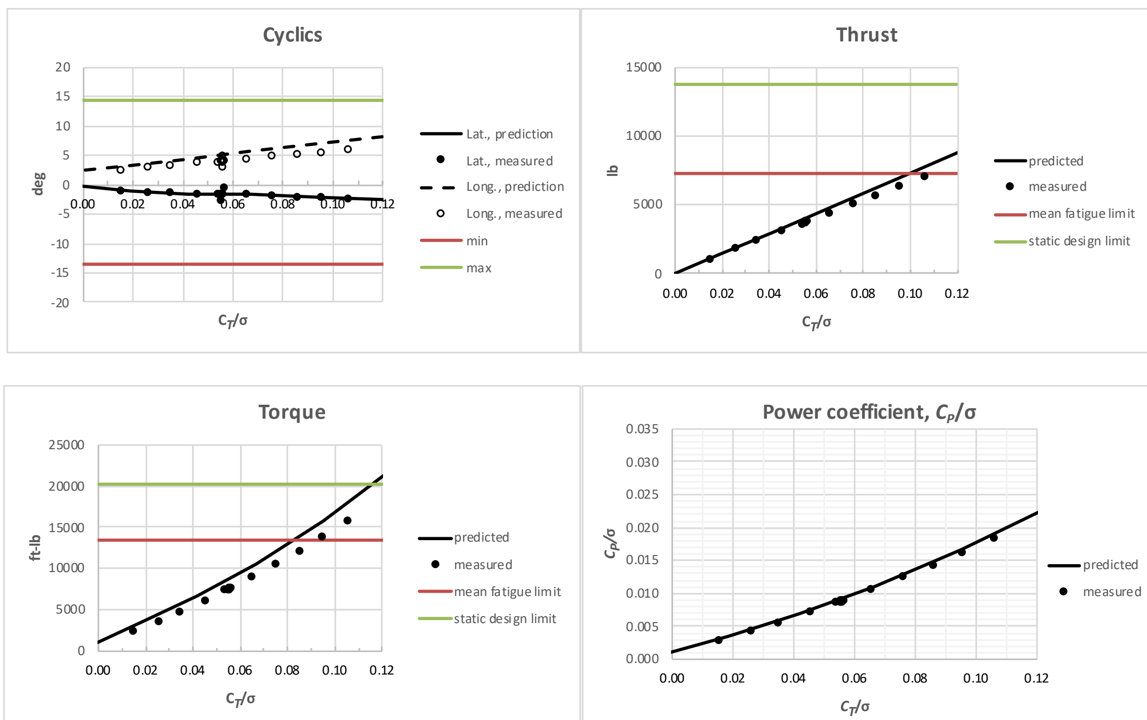


Figure 3a. Conversion 45-deg yaw correlation, V=92 knots (μ=0.200), rotor performance.

Figure 3b shows the mean and ½ peak-to-peak correlations for the pitch link load, midspan blade flap and lag moments, and the yoke inboard flap and lag moments.

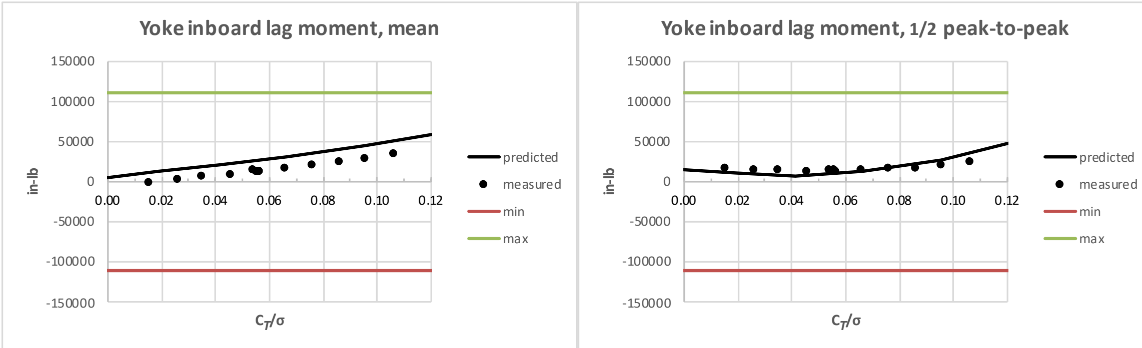


Figure 3b. Conversion 45-deg yaw correlation, V=92 knots (μ=0.200), mean and ½ peak-to-peak quantities.

The current 45-deg yaw conversion correlation is reasonable. The paper will include correlations at other yaw angles.

Concluding Remarks

Correlation of full-scale 699 proprotor performance and loads was presented; cruise (airplane) and conversion modes were covered. The comprehensive analysis CAMRAD II and recently acquired wind tunnel test data were used. The paper will contain the full-set of correlation results and details. No limitations on publication of TTR test data are anticipated.

Acknowledgments

Bell Helicopter has been deeply involved with the Tiltrotor Test Rig right from its inception and also with the 699 research proprotor; the authors gratefully acknowledge the technical support given by Bell Helicopter.

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